NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO

SUBCONTRACT NO. ACO-9-29067-01 PROCESS DESIGN AND COST ESTIMATE OF CRITICAL EQUIPMENT IN THE BIOMASS TO ETHANOL PROCESS

REPORT NO. 99-10600/13
BALED FEEDSTOCK HANDLING SYSTEM

REVISION 1W
OCTOBER 11, 2000

PREPARED BY:

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1. OBJECTIVE

The objective of this study is to design a system that will:

- Unload baled corn stover from trucks to short term (72 hour) storage
- Unload and convey bales from short-term storage to processing.
- Unwrap bales.
- Break up bales and wash to remove dirt and grit from corn stover that may have an adverse effect on downstream equipment.
- Downsize feedstock size to allow further processing in the 1st stage hydrolysis reactor.

2. SUMMARY

Three alternative systems have been identified for processing corn stover to supply feedstock to the 1st stage hydrolysis reactor. The equipment for each of the systems has been identified and preliminary sketches of the systems are included in this report. Summaries of the alternatives are as follows.

Alternative 1, the recommended system, is a wash table/shredder-based system. Unwrapped bales are conveyed to a wash table, which both breaks up bales and washes dirt and grit from the corn stover. The washed stover is then transported via conveyor past a metal detector and then introduced first to a primary shedder and then a secondary shredder where the material is reduced to the desired size and then conveyed to the hydrolysis process. Dirty wash water is recycled and cleaned utilizing a clarifier-thickener. Underflow from the thickener is dewatered in a belt press. Wash tables are commonly used in the sugar processing industry to wash sugar cane prior to processing. This system will deliver clean, relatively dry, shredded feedstock to the process with a cost-effective system.

Alternative 2 is a pulper-based system. Unwrapped bales are conveyed directly into a pulper tank, where the corn stover is mixed with water and forced between the rotor and stator of the pulper, which slices the stover into small pieces. Large heavy tramp material is collected from the bottom of the pulper chest and discarded. The corn stover slurry is then pumped through a centrifugal cleaner which removes the dirt. A screw drainer removes excess water and the material is sent to the pre-steaming vessel. This process ensures good cleaning of the corn stover by washing and is currently used for processing wheat straw in a pulping plant in Italy.

Alternative 3 uses a tub grinder hammer mill system followed by a washing cycle. In this system the unwrapped bales are broken and then shredded in a tub-grinder, hammer mill system. The cut stover is then washed in a system similar to conventional wood chip washing.

The wash-table/shredder based system, Alternative, 1, is recommended. The system will clean and downsize the stover, producing a low moisture content feedstock. System water consumption is low. The system is relatively simple and has relatively low capital cost.

Alternative 2, the pulper based system, will thoroughly clean the stover before entering the hydrolysis stage. However, the feedstock will have relatively high moisture content. Water use will be high and the capital cost of the system will be high.

Feeding dry corn stover into a tub grinder hammer mill, Alternative 3, is not recommended due to the problem of dust generation and relatively high moisture content of the feedstock after washing.

3. INTRODUCTION

Three alternative systems have been identified for processing bales corn stover into uniform washed feedstock to the hydrolysis process. The alternatives are described in this report and the advantages and disadvantages of each are reviewed.

The bale receiving and off-loading from trucks is common for each system and is described first.

4. RAW MATERIAL

The assumption for the in-coming corn stover raw material is that it will be cut corn stalks baled in either square or round form, The cut length of the corn stover has not been established at this time. The bales will be wrapped with plastic net and may also have a plastic film wrap. Two types of bales will be used, square and round. The bales will have the following sizes.

- Square Bales: 4 ft x 4 ft x 8 ft – 1200-1500 lbs.
- Round Bales: 70 inches diameter x 5 ft. long – 1200 lbs.

Design criteria for the feed material are shown in Table 1.

Table 1: Raw Material Feed Design Criteria

Item	Units	Quantity
Corn Stover, BD	MT/D	2,000
Moisture Content	%	15
Corn Stover, as is	ST/D	2,594
Bale weight, as is	Lb	1,200
Number of bales	Bales/hour	180

5. RAW MATERIAL RECEIPT

The corn stover bales are received from off-site storage on trailers. On-site storage is provided equivalent to 72 hours of production on an outside storage area. Bales and surrounding access ways as well the transport conveyors will be on a concrete slab. A concrete slab is recommended because of the volume of traffic required for the large volume of corn stover that is required. A concrete slab will minimize the amount of standing water in the storage area, as well as reduce exposure of corn stover to dirt. The stored material serves as a short-term storage for weekends, holidays and should normal direct delivery of material into the process be interrupted. The material in this storage is rotated continuously – the oldest material is processed first.

Short-term storage is fed directly from trucks received eight hours daily, six days a week. Bales are off-loaded by fork/clamp trucks and are placed in the short-term storage area or directly onto the bale transport conveyors. Bales are reclaimed from short-term storage by fork/clamp trucks and loaded onto bale transport conveyors. Bales travel to bale unwrapping stations and unwrapped bales are transported via conveyor for further processing.

It is assumed that long-term storage will consist of uncovered piled rows of bales and wrapped corn stover storage at a location or multiple locations in reasonable close proximity to the ethanol facility. Approximately 400 to 500 acres will be required for 11 months of storage depending on row height and spacing.

See Appendix A for a sketch of the proposed short-term storage area.

Truck receiving and storage capacities are estimated as shown in Table 2.

Table 2: Raw Material On-site Storage and Receipt.

Item	**Units**	**Quantity**
Corn Stover, as is	ST/D	2,594
Bale weight, as is	Lb	1,200
Number of bales	Bales/hour	180
Truck Loading	Bales/Truck	30
Weight per Truck	ST/Truck	18
Truck Unloading Rate, 8 hr x 6 day basis	Trucks/hour	21
Number of unloading lines	Ea.	2
Material Flow Bale - Transport Conveyor Capacity	ODST/hour/line	108
Number of Bales on each bale transport conveyor for 15 min buffer	Ea.	27
Short Term Storage	Hours	72
Stover Storage Required, as is	ST	7,776
Number of bales in storage	Ea.	12,960
Storage area based on 4 bale high piles	Acres	4.3

6. ALTERNATIVE 1 – WASH TABLE/SHREDDER

Unwrapped bales are conveyed to a wash table, which breaks bales as they are loaded on the table with a spreader bar. Water is sprayed as corn stover is conveyed up the 45 angle wash table. This washes dirt and grit from the product and allows water to drain from the stover. Washing the stover prior to cutting or shredding will minimize the amount moisture that is absorbed by the product. The washed stover is then discharged onto a conveyor, passes a metal detector, and is then introduced first to a primary shedder and then, subsequently, to a secondary shredder where the material is reduced to the desired size. The feedstock is then conveyed to the hydrolysis process. Some moisture reduction is expected to take place in the shredder.

Honiron, the wash table vendor contacted for this application, typically makes wash tables for the cane industry in the 22' to 26' wide range. A 24' cane table will handle up to 4500 tons per day of cane – 3500 tpd at best washing efficiency. Since corn stover is less dense than cane, 2000 metric tons per day is a reasonable size for a 24’ wide machine. The practical minimum wash table size is 8-foot width. The practical maximum limit for machine width is 30 feet. However, multiple machines are recommended to provide operational redundancy for increased capacity requirements. Mass flow is used as basis for sizing wash tables.

Dirty wash water is recycled through a clarifier-thickener to remove solids. Underflow from the thickener is dewatered in a belt press. The dewatered underflow is expected to be primarily topsoil and fines from corn stover. Wash tables are commonly used in the sugar processing industry to wash sugar cane prior to processing. This system will deliver clean, low moisture, shredded feedstock to the process with relatively low capital cost. Water consumption will be low.

Table 3: Design Criteria—Wash Table/Shredder Option

Item	**Units**	**Quantity**
Corn Stover, as is	ST/D	2,594
Number of Feed Lines	Ea.	2
Material Flow per Feed Line	ST/hour/line	54
Wash Water Flow	GPM/line	2,500
Estimated Solids Content Washed Stover	% Solids	60-70

A Class 40 Capital Cost Estimate, priced Equipment List and Process Flow Diagram for this option is in the Appendix. The overall capital cost for this option including short-term (bale storage, pre-engineered building to enclose process equipment, bale unwrapping, washing and shredding is $11,500,000.

The design power requirements for a process facility relative to the connected equipment horsepower depend on the level of sparing, batch versus continuous operation, the conservatism with which motors are selected for the application, in addition to other factors. Generally, the design power requirement falls between 70% and 80% of connected HP. As a basis for modeling HP demand for this portion of the facility, a factor of 75% of connected HP is recommended.

The operating labor requirement for this system is estimated to be as follows:

- 8 Mobile equipment (fork lift) operators 24 hours/day 7 days/week
- 1 Truck Traffic 8 hours/day, 6 days per week
- 3 Equipment operators (conveyors, bale unwrapping, wash table, shedder, clarifier-thickener, belt press, polymer system) 24 hour/day, 7 days/week.

7. ALTERNATIVE 2 – PULPER

The corn stover bales are placed on a transport conveyor from short-term storage, pass an automatic bale wrap removing station and are then are conveyed to a pulper chest. The stover is slurried in pulpers to 4% solids (96% water). The slurry is then forced through the pulpers where the straw stalks are cut by the pulper blade into pieces suitable for pumping, typically less than 1-inch length.

The pulpers are provided with discontinuous discharge junk traps to remove large heavy contaminant materials such as rocks and metal.

The corn stover slurry is pumped from the pulper to an inclined screw drainer and then to screw presses via a surge bin. The material is then transported to the hydrolysis process.

The water collected from the inclined drainer is recirculated through a clarifier thickener. The underflow from the clarifier-thickener is pump to a belt press where it is dewatered. Filtrate from the belt press is returned to the inlet of the clarifier thickener. Pressate from screw presses is pumped directly to the water tank. Water is lost with the dirt and feedstock, so fresh make-up water is required.

Table 4: Design Criteria – Pulper Option

Item	Units	Quantity
Corn Stover, as is	ST/D	2594
Number of Feed Lines	Ea.	4
Material Flow	ST/hour/line	46
Wash Water Flow	GPM/line	2,200
Estimated Solids Content Washed Stover	% Solids	45-55%

An Equipment List and Process Flow Diagram for this option are in the Appendix.

8. ALTERNATIVE 3 – DRY HOGGING

In this option the unwrapped bales are dry disintegrated and cut in a tub grinder hammer mill system. The cut stover is washed in a system similar to conventional chip washing.

Dry opening and cleaning of agricultural material for pulping has been used in a Danish mill and in the pilot operation tested by Weyerhaeuser Company in Springfield, OR. Both these systems use a bale breaker/tub grinder to open bales then feed the material to a chopper or milling machine to reduce the particle size, in these examples processing straw to a fine cut of 5-20 mm particle size. The milled material is then dry-screened to separate and remove fine material consisting of dirt and fines undesirable for pulp manufacture. Part of the objective of the milling was to reduce the stalk nodes to fines as the nodes produce poor quality pulp.

For the present project, fine milling and removal of fine plant material is not required. However, removal of dirt is necessary and wet washing is considered to be the most efficient way to do this. Dry hogging to a 1-3” cut length could be used prior to a wash stage. The wash stage would then not need to have a cutting action and could be similar to chip washing systems used in standard practice for TMP pulp mills.

Bales are placed on the feed conveyor and pass through an unwrapping station. The bales then drop to a tub grinder with a hammer mill to open the bales and reduce the size to 1-3”. The cut material feeds into a washer tub with agitator. The bottom of the washer tub has provision for removal of heavy material.

From the washer tub, the slurry is pumped through centrifugal sand cleaners to an inclined screw drainer. After draining excess water, the material is discharged into a live bottom bin to control and level flow and then is fed to the hydrolysis process.

Design details for this dry milling and washing system are shown in Table 5, below.

Table 5: Design Criteria—Dry Milling Option

Item	Units	Quantity
Corn Stover, as is	ST/D	2594
Number of Feed Lines		4
Material Flow	ST/hour/line	27
Wash Water Flow	GPM/line	2,000
Solids Content Washed Stover	% Solids	10-20

The major process equipment downstream of bale unwrapping consists of:

- Inclined conveyor. 60' x 8', 20 elevation to feed Hog/grinder
- Hog/grinder
- Metal trap
- Washer vat
- Repulper to drainer conveyor/pump, 2000 g/m
- High Density Cleaner
- Wash water recirculation and cleaning system, 1800 g/m
- Centrifugal cleaners
- Chests – 2
- Sand and rock disposal skip
- Drainer, inclined screw
- Surge bin (expected to be needed to control feed to the hydrolysis process). Could also be a surge conveyor)

9. DISCUSSION

Most of the items of equipment specified in the options above are or have been used in straw or corn stover processing in commercial operations or in sugar cane processing. Some items such as automatic unwrapping plastic wrap from the bales are not currently practiced. Hogging is undertaken in tub grinders but these are mostly designed for low volume farm use rather than high volume continuous industrial applications. These items require some further development and resolution and are described in more detail below. Hammer mills are used in a range of industrial and municipal applications.

The acceptable moisture content of the material forwarded to the hydrolysis process has not yet been defined. The recommended wash table/shredder system described above is expected to yield material with 60-70% solids content after shredding.

Unwrapping

Cross Wrap OY, Finland, have de-baling technology but this would have to be modified for the stover bales wrapped with plastic net and film. Cross Wrap have bale-wrapping systems for plastic film.

Manual bale unwrapping is feasible but labor intensive. It would be accomplished by having bales place on the floor next to a sunken conveyor trough. A set of bales would have their wrap manually cut then the plastic removed or secured. The baled material would then be pushed into the conveyor by a bulldozer.

Hammer Milling

Hammer mills are used in a range of industrial and municipal applications. However, testing of hammer mills on the corn stover is recommended to verify equipment applicability and sizing. The optimal size range of material required for hydrolysis has not been established and will be necessary to define the necessary shredding equipment.

Hogging

United Milling, Denmark, produce a disc mill, which was used to reduce straw in the Weyerhaeuser, Springfield project. However, this mill produces a finely cut material for screening fractionation, which is probably more than is needed for the Biomass Energy system. Tub grinders are available for farm use and industrial strength tub grinders are available on a limited basis.

10. COMPARISON OF ALTERNATIVE SYSTEMS

Comparison of the three alternative systems described above is shown in Table 6 below.

Table 6: Comparison of Advantages and Disadvantage of Alternative Systems

	Wash Table and Shredder Alternative	**Pulper Alternative**	**Dry Hogging and Wash Alternative**
Dust generation	Low	Low	High
Water use	Low	High	High
Large contaminant removal	Good	Excellent	Good but hog not protected
Small dirt removal	Good	Good	Good
Fines loss	Low	Medium	High
Solids content out of drainer	Not applicable	10-20%	10-20%
Solids of feedstock to 1st Stage Hydrolysis	60%-70%	*45-55%	*45-55%
* With screw press dewatering equipment			

11. EQUIPMENT SCALING FACTOR

Capital costs for applications with larger or smaller capacity may be approximated using the following ".6 rule" as a basis:

$$P_2 = P_1(C_2/C_1)^{.6}$$

Where, P_1 is the cost of a plant with capacity C_1 and, P_2 is the price of plant with capacity C_2. A capital cost estimate based on this equation is expected to have lower accuracy than the original estimate.

11. RECOMMENDATIONS

1. The Washer/Shredder Alternative is recommended as the best method for achieving a combination of good cleaning of the stover with uniform material size, low moisture content and relatively low capital cost.
2. The Pulper Alternative would provide cleaner feedstock. However the moisture content of the feedstock would be significantly higher, even with heavy-duty screw presses. The capital cost of the Pulper Alternative is expected to be approximately 2.5 to 3 times the cost of washer shredder Alternative.
3. Dry hogging is not recommended due to the problem of dust generation.
4. Further investigation of bale unwrapping is needed. While the proposed vendor states that they can provide a bale unwrapping system, they have never built such a system. It is recommended that a prototype bale unwrapping unit be built and tested to verify feasibility, equipment capacity and cost.

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